Virtual Reality Visualization of Accelerator Magnets

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Abstract: We describe the use of the CAVE virtual reality visualization environment as an aid to the design of accelerator magnets. We have modeled an elliptical multipole wiggler magnet being designed for use at the Advanced Photon Source at Argonne National Laboratory. The CAVE environment allows us to explore and interact with the 3-D visualization of the magnet. Capabilities include changing the number of periods of the magnet displayed, changing the icons used for displaying the magnetic field, and changing the current in the electromagnet and observing the effect on the magnetic field and particle beam trajectory through the field.

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1 Introduction

Electromagnetic field analysis and design are more difficult in three dimensions than in two, because the mathematics is more complex and the amount of data is greater. Visualizing the computational mesh and the results of the electromagnetic calculations is also a more difficult task. A virtual-reality environment such as the CAVE (CAVE Automatic Virtual Environment) can help make the visualization of 3-D meshes and computations more usable for designers and users of magnets and other electromagnetic devices.

In this paper we discuss an application of the CAVE [1] as an aid to the design of accelerator magnets. The Advanced Photon Source (APS) is a synchrotron radiation facility that is being constructed at Argonne National Laboratory. As part of this project a number of insertions devices, special magnets called "wigglers" and "undulators," are being designed to bend the positron (particles like electrons, but positively charged) particle beam that travels in a circular path around the APS storage ring.

When a positron beam is "wiggled" by a wiggler magnet, radiation is emitted in the form of x-rays. The particular design of a wiggler magnet determines the brightness and spectrum of the x-ray radiation emitted. This high-energy radiation will be used by scientists to perform experiments in many fields.

The design of such magnets is complicated by the three-dimensional aspects of the problem, the need to generate a particular spectrum of the radiation emitted, the variety of design parameters that exist, and the amount of computation time involved in parametric design studies. The purpose of our work was to develop tools to assist scientists involved in the design and use of accelerator magnets. In particular, we discuss here the CAVE environment as an aid to visualizing an elliptical multipole wiggler magnet.

2 The CAVE

A virtual reality system provides immersion and interactivity. *Immersion* can be achieved through wide field of view, stereo display, and viewer-centered perspective. *Interaction* refers to the real-time involvement the user must have with the perceived environment. The motivation is to take advantage of the human ability to process 3-D spatial information [2].

The CAVE is a virtual reality system being developed at the Electronic Visualization Laboratory at the University of Illinois at Chicago that implements the concepts of immersion and interaction through the integration of a number of components. Wide field of view is achieved by creating an environment where the user is surrounded by computer imagery projected on the walls and floor of a ten-foot cube. Left- and right-eye stereo views are sequentially computed and displayed on the current configuration of two walls and the floor. A person standing inside the cube wears LCD shutter glasses to see the images in true three-dimensional space. The user is tracked by an electromagnetic tracking system, so his/her instantaneous position and orientation are known. This allows the environment to be rendered in correct viewer-centered perspective. The user is able to manipulate objects within the CAVE by using a wand, a three-dimensional analog of the mouse of current computer workstations. The CAVE also allows multiple users to share the virtual environment by donning a pair of shutter glasses and stepping into the cube structure. Figure 1 is a picture of the CAVE environment.

3 Elliptical Multipole Wiggler Magnet

The Advanced Photon Source is a synchrotron radiation facility, funded by the U.S. Department of Energy, that is being constructed at Argonne National Laboratory. The APS will produce extremely brilliant x-ray beams that will allow scientists to study smaller samples, more complex systems, and faster reactions and processes than ever before. X-rays are produced by generating positrons and accelerating them to raise their energy to seven billion electron volts (7 GeV). The positron beam orbits at 7 GeV around the APS storage ring.

Special arrays of magnets called insertion devices manipulate the positron beam in order to fix its energy and increase its brilliance. Insertion devices can be either wigglers or undulators, depending on the effect they have on the movement of the positron beam. Wiggler magnets produce very intense, energetic radiation over a wide range of energies, while undulator magnets yield radiation of selected energy at high brilliance. These tuned x-ray beams are further processed by optical instrumentation before they illuminate the sample being studied.

The visualization of one such magnet, the elliptical multipole wiggler (EMW), is the subject of our work. The EMW [4] consists of a hybrid-magnet wiggler providing a vertical field and an electromagnet providing a horizontal field, with the poles of the two magnets 90 degrees apart. (In a hybrid magnet, permanent-magnet material generates the field, and steel poles shape it.)

Figure 2 shows a (simple) half-period of the EMW magnet. One pair of poles and coils for the electromagnet is shown on the left and right. One pair of permanent magnets is on the top and bottom. One pair of half-poles for the hybrid magnets (the permanent magnet material plus steel poles) is at the front, and another pair is at the back. Note that the hybrid magnet poles and electromagnetic poles are a quarter-period apart. In the current design, the vertical pole gap is 24 mm, and the horizontal pole gap is 71 mm. The peak vertical field is 0.9 tesla, and peak horizontal field is 0.1 tesla. The EMW array consists of a total of 18 periods.

4 Implementation

This section discusses the implementation of the elliptical multipole wiggler magnet using the CAVE environment.

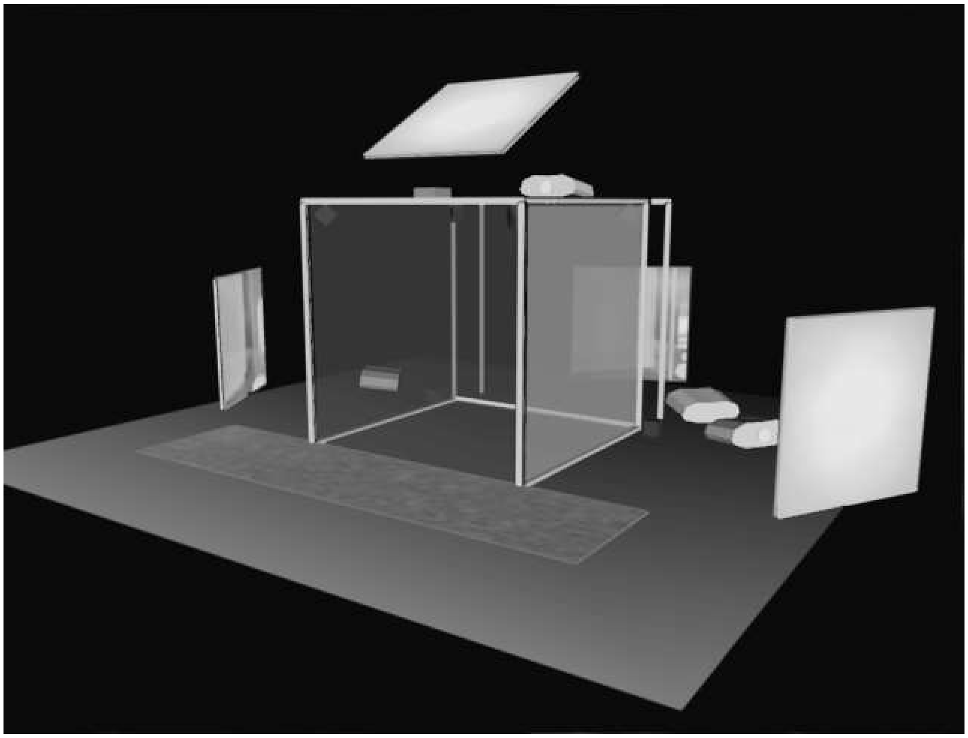

Figure 1: The CAVE virtual reality environment. Computer images sent to the projectors are folded by mirrors and directed onto the CAVE walls and floor. This configuration decreases the space requirement for the CAVE.

4.1 Magnetic Field Calculation

Using Vector Fields Inc.'s TOSCA program, we conducted electromagnetic field computations for the EMW magnet. The geometry was reconstructed by using the code CORAL [3]. (In other applications CORAL has been used for the electromagnetic field computations as well.)

4.2 Magnet Geometry Display

Currently, the user can vary the number of half-periods displayed from zero to four. This display of the magnet gives the physical context in which to display the calculated magnetic field. Figure 3 from the CAVE simulator displays four half-periods.

4.3 Magnetic Field Display

In order to visualize the magnetic field, an icon is used to represent the field value. The field is displayed in the interior of the EMW on a 3-D grid of points. The icon displayed is either a cone or a cylindrical bar. The icon is oriented in the direction of the magnetic field at that point in space. The icon's color and size are a function of the vector's magnitude at that point.

The user can interactively change the number of icons used to display the magnetic field. This capability can be useful when there are many 3-D grid points and the number of icons overwhelms the user's ability to comprehend the results. For a similar reason, we display only one half-period of the magnetic field, irrespective of the number of half periods of the magnet that are displayed.

The current in the electromagnet can be varied dynamically. By observing the changes in the resulting field calculations, the user can understand the relationship between the electromagnet's field strength and the orientation and magnitude of the resulting vector field.

4.4 Particle Path

The trajectory of the positron beam as it traverses the EMW is confined to the horizontal plane when the electromagnet is turned off, and high-intensity x-rays will be emitted at the extremas of the particle excursions. When the electromagnet is turned on, the positrons start to move in a helical path, and the emitted radiation will now be elliptically polarized (when viewed on-axis). The helicity is controlled

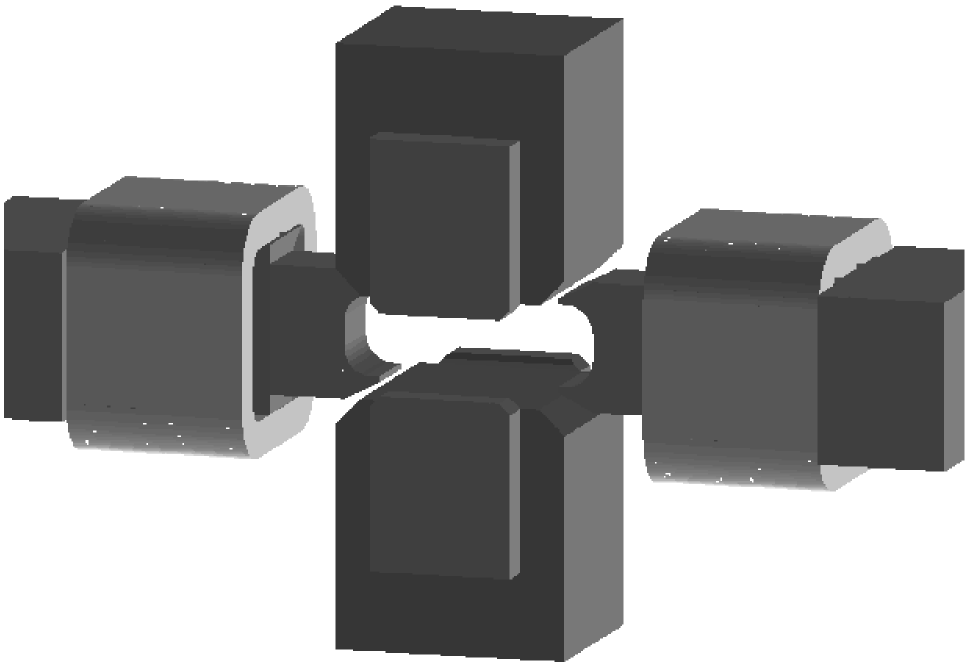

Figure 2: One half-period of the elliptical multipole wiggler. One pair of poles and coils for the electromagnet are shown on the left and right. One pair of permanent magnets are on the top and bottom. One pair of half-poles for the hybrid magnets is at the front, and another pair is at the back. Note that the hybrid-magnet poles and electromagnetic poles are a quarter-period apart.

by the strength of the current in the coils of the electromagnet. An alternating current produces a time-modulated elliptical polarized light, which is an important tool in the study of many magnetic materials.

The particle beam trajectory through the EMW magnetic field was calculated and is displayed during the simulation. A tracer sphere dynamically follows the calculated trajectory. At the maximum/minimum excursion in x (which occurs when the beam passes through the permanent magnet poles), the simulation displays a flash to indicate that energy is emitted.

Figure 4 shows a display from the CAVE simulator showing the path of the positron beam through the magnetic field. When displaying the trajectory we use a scale factor in the x (horizontal) and y (vertical) directions to enhance the visibility of the beam. The trajectory is not scaled in the z dimension in which it travels. The scale factor is rather large in relation to the size of the magnets because the trajectory motions are on a micron scale.

When the user changes the current in the electromagnetic, the path of the positron beam is changed. The effect is a linear scaling of the strength of the magnetic field in the horizontal direction. This causes a linear scaling in the vertical component of the trajectory.

4.5 User Interface

The user interacts with the data via a 3-D interface. A menu is displayed on the left wall to indicate the user's choices. This is similar to the traditional workstation 2-D menu. However, the process of picking a menu item requires the use of the 3-D wand.

As mentioned earlier, the wand is a hand-held device with three buttons and a joystick. The user points the wand at the desired menu item and clicks the left button to choose it. Choosing a menu item toggles a mode on or off. When a menu item is selected, the wand is given the ability to execute actions specific to that menu item.

Currently, there are four menu items. The first toggles the icon used to represent the magnetic field between cones and cylindrical bars. The second specifies the number of half-periods to display, currently between zero (i.e., only the magnetic field is displayed) and four. The third specifies translation; when this item is toggled on, one can use the wand to push or pull the magnet and field to a desired location for viewing. Finally, the fourth menu item specifies the

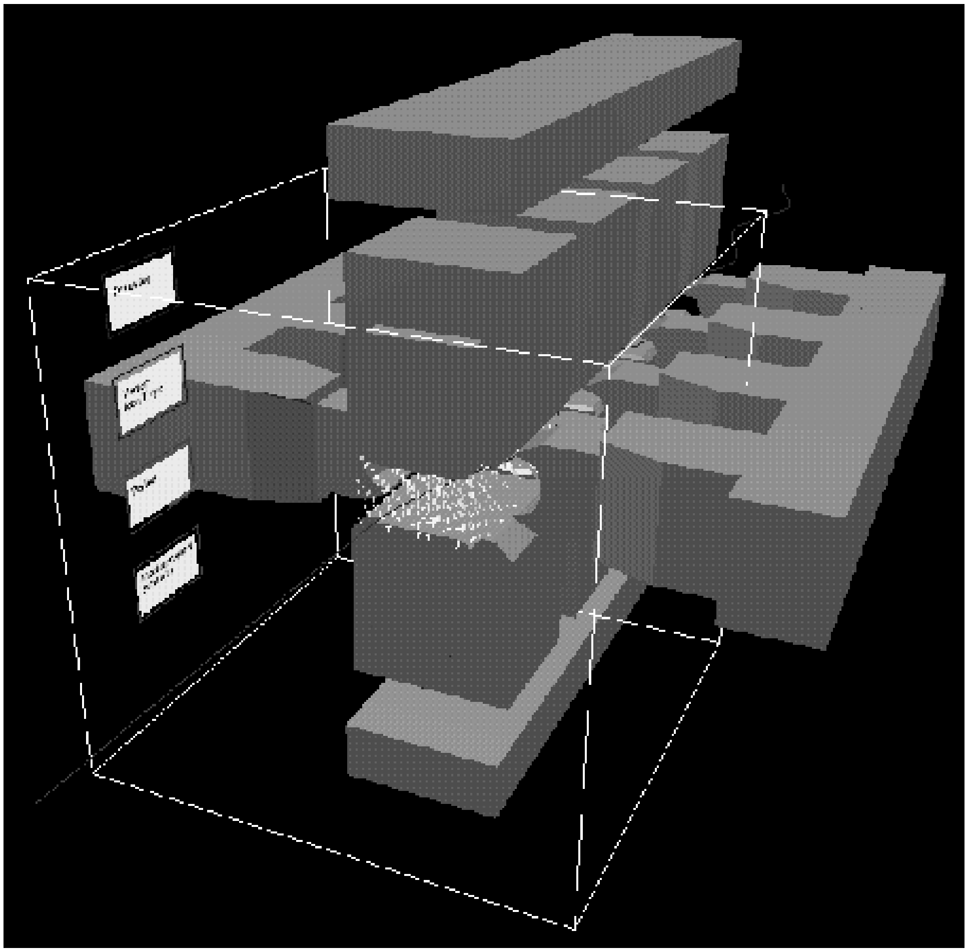

Figure 3: Four half-periods of the EMW displayed in the CAVE simulator

current in the electromagnetic.

5 Conclusions and Future Work

The CAVE is a new tool that we are using to visualize 3-D electromagnetic field calculations. We find it helps increase researchers' understanding of the field calculations, making the results of the computation more useful for designers and users of accelerator magnets.

A number of possibilities for future enhancements exist. One would be to use flux lines or flux tubes to represent the magnetic field. Another would be to introduce cutting planes of any orientation to show the field variation. These cutting planes could also be used to study saturated regions in the magnet's iron. We could also vary the starting position and angle of the positron beam to explore the edge effects felt by the particle beam as it enters the field of the wiggler magnet.

We are also interested in integrating the CAVE display with real-time electromagnetic field computations using CORAL on the IBM SP massively parallel computer. This capability would enable us, for example, to study issues such as magnetic and mechanical interference between neighboring accelerator magnets or to trace trajectories through a series of accelerator magnets. Also, an enhanced CORAL is being developed to model eddy currents; we plan to use this to study how eddy currents distort the field in the bore of a wiggler magnet.

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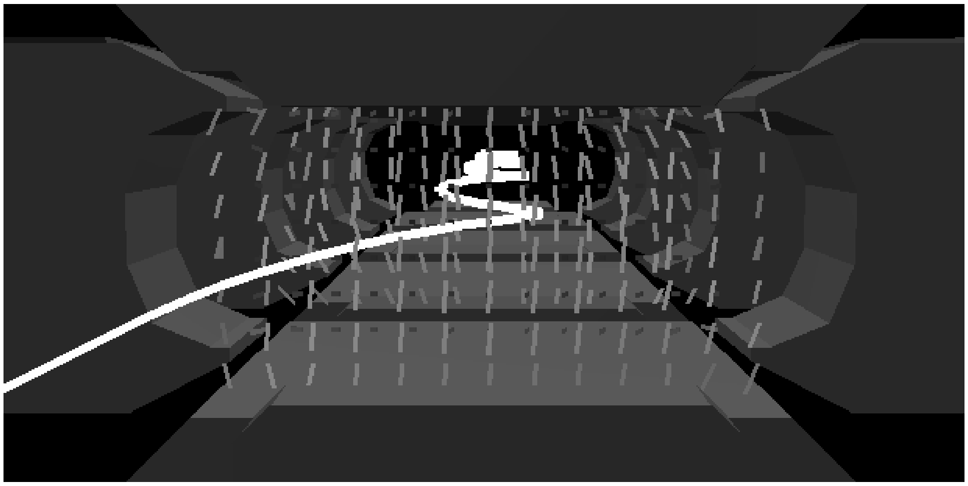

Figure 4: Path of the positron beam displayed in the CAVE simulator

codes available to us.

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